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50. Internationales Wissenschaftliches Kolloquium
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Connecting Costumer to the Design - Approach on the Example of the Development of Modular Handling Systems

ABSTRACT

In the present paper points of customer involvement in the product development process are identified and explained considering different product customization types. Some methods for customers needs identification are discussed. A systematic approach to connect customers in the development which capture of the specific customer needs, maps and translates these as functional requirements is presented. It is explained how using of Virtual Manufacturng-methods and techniques as well the the Internet within product customization will facilitate the whole product design process. A web-based framework connecting customer in the product configuration developed as part of on-going research with a manufacturing company that produces positioning and handling systems is presented. Some advantages of the proposed approach are summarized.

INTRODUCTION

The new products are introduced to the market traditionally trough the "Design-Make-Sell"-cycle, typical for manufacturing industries. Manufacturers capture and aggregate customer needs to product specifications, pass the information to the designers to design the product, produce it and display it for sale. The long cycle time is not enough responsive to the specific needs of today's dynamic and competitive markets concentrating on small number final products increases the risk of misjudging the real customer needs [1]. On other hand customers are the initiation point of the whole product value chain and therefore it is very important to correctly identify the customer needs and provide them with sufficient information to facilitate their decision-making process.

In order to overcome the above mentioned problems many companies from different industrial branches (e.g. Kodak, Sony, Boeing etc.) are using module or scale based product families to reduce development costs and time-to-market while increasing product variety and customization [1-5].

A product family is a group of related products that is derived from a common set of components or subsystems (called inventory or platform) in order to satisfy a variety of customer requirements while reducing development and manufacturing costs, and time-to-market. Such approach offers new possibility to facilitate customers' direct participation in the product development process and to provide clear identification of their specific needs [1,2].

Consumers' knowledge and direct participation in the design process leverages product and product related information, facilitates marketing research and brings different customers' attitudes towards buying decision making. As a consequence, the traditional cycle of design – make – sell will be replaced by the new one of design – sell - make. Consumers design the product, buy it, and send the order to be manufactured; this will create a new product design and development process, which benefits both customers and manufacturers. In this evolvement manufacturers are able to gain advantages, reducing amount of iterations caused by unsatisfactory products, and building up a knowledge base and providing a more effective product knowledge transfer from the product development process to the sales-delivery process.

PRODUCT CUSTOMIZATION

Product customisation is defined and classified based on two characteristics: *point in the production cycle of customer involvement and type of product modularity employed.*

Each customization configuration exhibits a distinct approach to the manufacture of the customized products. If customers are involved in the early design stages of the production cycle, a product could be highly customized. If customer preferences are included only at the final assembly stages, the degree of customization will be not as great. Point of customer involvement provides an indicator of the relative degree of product customization.

In [3] a typology is presented according which customization has one of three forms (see Table 1). Each form differs in the portion of the production cycle involved and the degree of uniqueness of the product. The type of customization chosen by the producer implies different levels of customer involvement in product design and different points at which that involvement begins.

Customization degree	Customization type	Product type	Life-cycle stage	Features
High	***Pure customization***	Highly customized product	Entire product life cycle	Products are designed and produced from scratch for each individual customer, includes
	Tailored customization	Modified standard product	Manufacturing	Alteration of basic product design to meet specific customers needs
Low	***Standardized customization***	Product with set of features and options	Assembly and Delivery	Products are assembled from predetermined list of standard components

Table 1 Customization types

One the other hand customization requires that products be provided in a cost-effective manner. It is accepted that modularity is the key to achieving low cost customization [4]. A modular approach can reduce the variety of components while offering a greater range of final products.

They are different modularity types found in the production environments. In [5] they could be distinguished in the 6 groups (see Table 2):

Customization degree	**Modularity type**	**Component type**	**Life-cycle stage**	**Features**
High	***Component-sharing***	Original design	Design Manufacturing	Products are uniquely designed around a base unit of common components
	Cut-to-Fit	Modified design	Design Manufacturing	Altering dimensions of modules before combining with other modules.
	Component-swapping	Standardized and repeatable	Assembly Use	Modules are selected from a list of options to be added to the base product
	Mixed	Standardized and repeatable	Assembly Use	Similar to Component-swapping, but modules lose their unique identity when combined
	Bus	Standardized and repeatable	Assembly Use	Ability to add module to an existing series, when one or more modules are added to an existing base
Low	***Sectional***	Standardized and repeatable	Assembly Use	Arranging standard modules in a unique pattern

Table 2 Typology of modularity according to [5]

These different types of modularity can be assigned to the phases of the product cycle [3]. Within design and manufacturing stage, modules can be altered or components can be fabricated to provide for the specific requirements of the customer (Cut-to-fit and component sharing modularity). Within assembly and use stages, modules are configured according to customer specification, but components and modules cannot be be altered (Component swapping, sectional, mix, and bus modularity). In particular, sectional modularity can also be used in the post-production phases where the customer combines components across manufacturers. Sectional modularity may require adoption of uniform industry standards.

When modularity is employed in customized products, product distinctiveness is a result of either the combination of standard modules into a finite number of permutations or the alteration of prescribed modules into a limited range of products. In contrast, purely customized products are infinite in permutations [3].

Customers must be involved at one or more points in the product realization process in order for the product to be fully customized (see Fig.1).

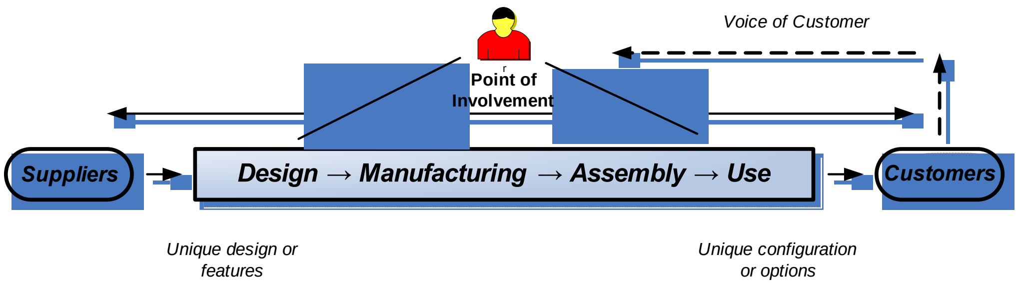

Figure 1 Points of customer involvement in the product development according to [1,3]

Another possible typology of the customization is based on the two key dimensions: modularity and customer involvement (Fig. 2). According [3] juxtaposition of customer involvement and modularity used creates four groups of customization types (Table 3).

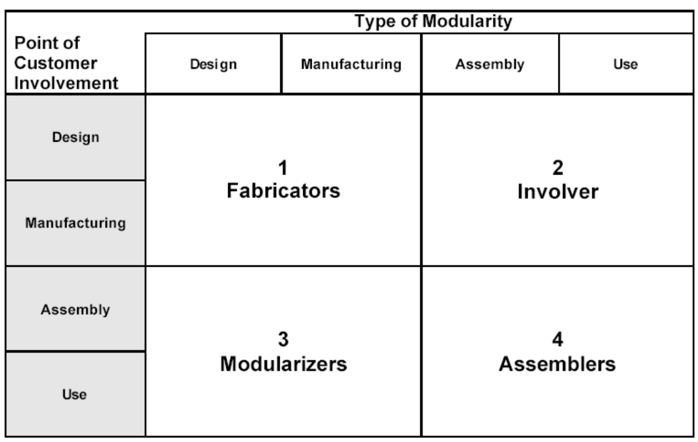

Figure 2 Customization configurations according to [3]

Customization type	***Customer involvement***	***Modularity type***	***Customization strategy***	***Features***
Fabricators	Design Manufacturing	Cut-to-Fit Component sharing	Pure customization	Unique components may be designed for specific application.
Involvers	Design Manufacturing	Component swapping	Tailored customization	customization is achieved by combining standard models to meet the specification of the customer
Modulizers	Assembly Use	Component sharing Component swapping	Tailored customization Standardized Customization	development of a modular approach in the design and fabrication stages, although customers do not specify their unique requirements until the assembly and use stage
Assemblers	Assembly Use	Component swapping Mixed Sectional	Standardized Customization	Providing customization by using modular components to present a wide range of choices to the customer

Table 3 Customization types based on modularity and customer involvement

The customized products could be mapped according to the four key manufacturing modes: make-to-stock, assemble-to-order, make-to-order and and engineer-to-order (Table 4). Each of these methods has different implication on the product development process and associated technologies needed to deliver the customized product [1,3,6].

Manufacturing mode	***Features***
Make-to-Stock (MTS)	A process that produces standard products to be stored in inventory
Make-to-Order (MTO)	A process that produces products in response to a customer order, the firm does not keep any finished goods inventory. Typically produces products that are unique to the customers' requirements
Assembled-to-Order (ATO) (configured-to-order)	A process deploying a customer interface strategy that responds to a customer order by putting together standard components and modules.
Engineer-to-Order (ETO) (tailored-to-order)	A process in which the engineering is done in response to a customer order, Products are designed to the customer's specifications, components can be stock items or designed specifically to the order, On line engineering change order control with electronic approval process

Table 4 Manufacturing modes

Nowdays companies are transitioning from MTS to MTO or ETO operating modes to create demand-driven supply chains.

METHODS FOR IDENTIFYING COSTUMER NEEDS

There are many different methods to identify and structure costumer needs which are well known. The commonly used in the research and industry are *Quality Function Deployment, Kano Diagram, Voice of Customer, Kansei Engineering and Conjoint Analysis* [7].

Voice of the customer

The term *"voice of the customer" (VoC)* represents a set of customer needs arranged in a hierarchical manner in which customers assign priority for a given set of needs. *VoC* is referred to describe the stated and unstated customer needs or requirements. Traditionally, Marketing has had responsibility for defining customer needs and product requirements. This has tended to isolate Engineering and other development personnel from the customer and from gaining a first hand understanding of customer needs. As a result, customer's real needs can become somewhat abstract to other development personnel [8]. The *VoC* is captured and mapped in a variety of ways: direct discussion or interviews, surveys, focus groups, customer specifications, observation, warranty data, field reports, web-based elicitation etc.

Quality Function Deployment

Quality Function Deployment (QFD) is a technique introduced in Japan by Yoji Akao in 1966 and used extensively by Toyota. It represents a structured approach to defining customer needs or requirements and translating them into specific plans to produce products to meet those needs. QFD is usually represented as a set of matrices describing the relationship between data. The starting matrix, linking the voice of customers is referred as *House of Quality* [7,9]. (Fig. 2). This understanding of the customer needs is then summarized in a product planning matrix or "house of quality". These matrices are used to translate higher level "what's" or needs into lower level "how's" - product requirements or technical characteristics to satisfy these needs. First, customers' requirements (which form the vertical axis of the matrix) are matched with the design attributes (which form the horizontal axis of the matrix). The individual elements of the matrix are used to indicate the degree and direction of influence of the main design attributes on customer needs. To do this some kind of coding scheme is used. The correlation between different design attributes is recorded so that the consequence for other attributes of changing one attribute is understood. In addition, specific target values of each design attribute may be defined and, if the product or service is already in use, a competitive assessment comparing the product or service in question with competitors' offerings may be mapped.

The basic *QFD* methodology involves four basic phases that occur over the course of the product development process (Fig. 3). During each phase one or more matrices are prepared to help plan and communicate critical product and process planning and design information.

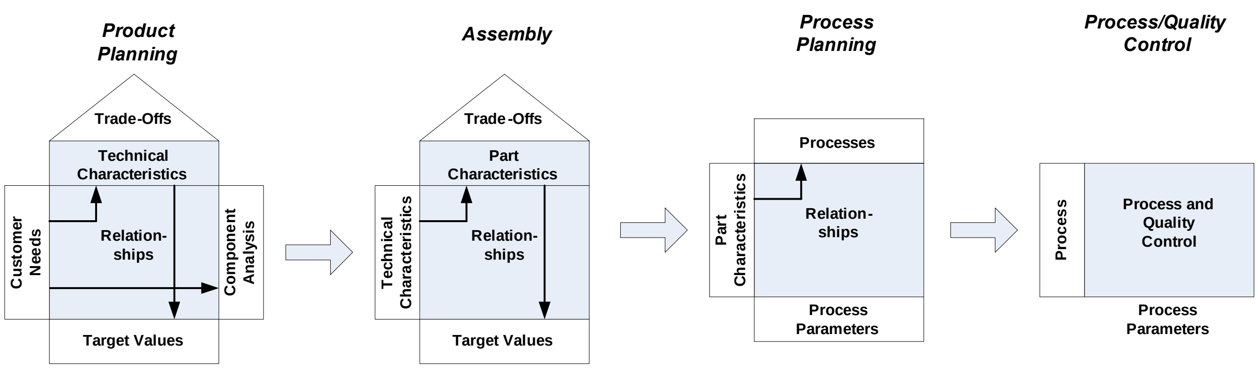

Figure 3 Basic phases of QFD

A disadvantage cited by practitioners is the complexity involved in using *QFD* in large design projects; the number of factors used in each axis of the matrix must be minimised if the process is not to become unmanageable. Conversely, if the number is artificially restricted too severely, important relationships may be overlooked [9].

Kano Diagram

Kano Model offers some insight into the product attributes which are perceived to be important to customers. It is used to capture and categorize the customer needs into three different regions based on the level of customer satisfaction related to the absence or presence of the features as follows:

- Threshold attributes, which must be present in order for the product to be successful
- Performance attributes, which are directly correlated to customer satisfaction.
- Attractive attributes, customers get great satisfaction from a feature - and are willing to pay a price premium [10].

Kano developed a structured user questioning methodology to help characterise different features and remove ambiguity by ensuring that categorisation is based on user research. The methodology is relatively straightforward an comprises following stages: Determine main features, which need to be classified; Devise questionnaire; Sum responses; Identify classification; Plot features onto the Kano graph.

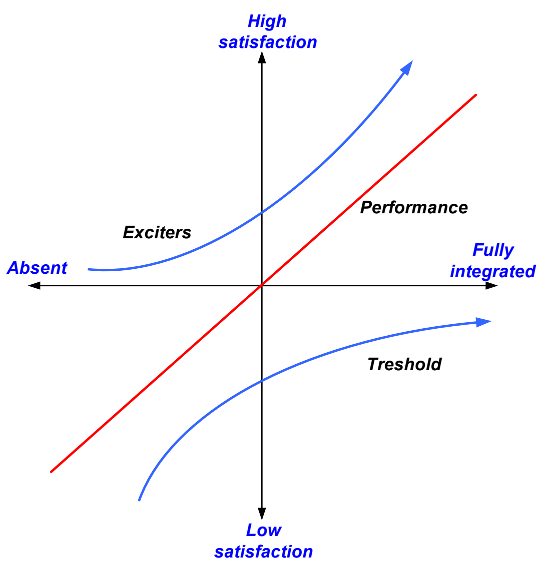

Figure 4 Kano Diagram

The features are mapped onto the diagramm and provide a visual guide to the relative importance from a user perspective of different aspects of functionality. *Kano Diagramm* assists in capturing and categorizing consumers' preferences and needs. By understanding treshold, performance and exciting needs, producers can focus their strategy to suit different segment of consumers.

Kansei Engineering

Kansei is a Japanese term which means psychological feeling or image of a product. *Kansei engineering* refers to the translation of consumers' psychological feeling about a product into perceptual design elements. *Kansei engineering* is also sometimes referred to as "sensory engineering" or "emotional usability." This technique involves determining which sensory attributes elicit particular subjective responses from people, and then designing a product using the attributes which elicit the desired responses [11]. Customers are asked to describe the product in their own words based on their subjective perceptions. These words are then broken down into subconcepts continuously until the sub-concepts can be translated into physical traits of the product.

Each product is rated on each attribute scale, and these ratings are statistically compared to provide a distribution of products across the different rating criteria. Analyzing all products rated highly on a particular characteristic allows you to draw conclusions about which perceptual elements are responsible for eliciting this subjective judgment.

Conjoint Analysis

Conjoint Analysis has been a standard marketing research technique regularly employed since early 70's. It is a research technique used to measure the trade-offs people make in choosing between products and service providers. It is also used to predict their choices for future products and services. *Conjoint Analysis* assumes that a product can be "broken down" into its component attributes. By understanding consumers' utility value of each attribute, the product provider can offer the best product that maximizes consumers' total utility value. The product utility function can be described by the following equations [7]:

$$U_r = \sum_{m=1}^{M} W_m \left(\sum_{l=1}^{Lm} d_{ml} X_{rml}\right) = \sum_{m=1}^{M}\sum_{l=1}^{Lm} U_{ml} X_{rml}$$
$$X_{rml} = \begin{cases} 1 & if \;\; attribute\, m\, is \;\; on \;\; 1^{th}\, level; \\ 0 & otherwise \end{cases} \tag{1}$$

where M is number of product attributes $Z_1, Z_2, \ldots, Z_M$ with L_m levels

U_r is consumer's utility for profile $r = 1, 2, \ldots, R$

W_m is the importance of attribute Z_m

These equations explain that a product can be represented as having M attributes, $Z_1, Z_2, \ldots, Z_M$, and each attribute can have L_m levels. The consumer's utility for profile r is represented by Ur, $r = 1, 2, \ldots, R$. W_m represents the importance of attribute Zm,d_{rml} represents the desirability for lth level of attribute m, $l=1, 2, \ldots, L_m$; $m = 1, 2, \ldots, M$; and U_{ml} represents the utility of attribute m's l-th level

X_{rml} is a dummy variable denoting whether the particular level of an attribute is being selected or not.

In general, when using conjoint analysis following can be obtained: Consumer selection behaviors; Devising a strategic plan for new product development; Devising a marketing strategy plan; Market share simulation.

DESIGN BY CUSTOMERS

Design by Customers (DBC) is a process in which customers are allowed to express their product requirements and carry out the mapping process to the physical domain of the product. It is comprises following two stages: *Customer s' Needs Identification&Structuring and Product Design*. [7]. presents a framework for structuring customer needs for *DBC* deploying some of the above discussed tools (Fig. 3). The process is divided into three stages:

- Elicitation of tacit, implicit or hidden customers' needs
- Translation identified customer needs in engineering oriented customers' requirements
- Enhancing the clarity of customers' needs

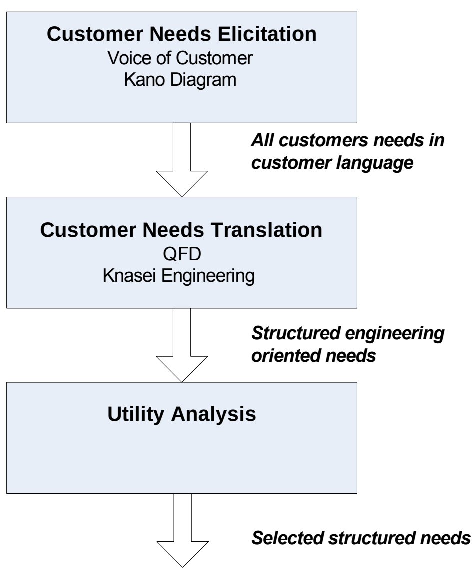

Figure 5 Framework for structuring customer needs for Design by Customer

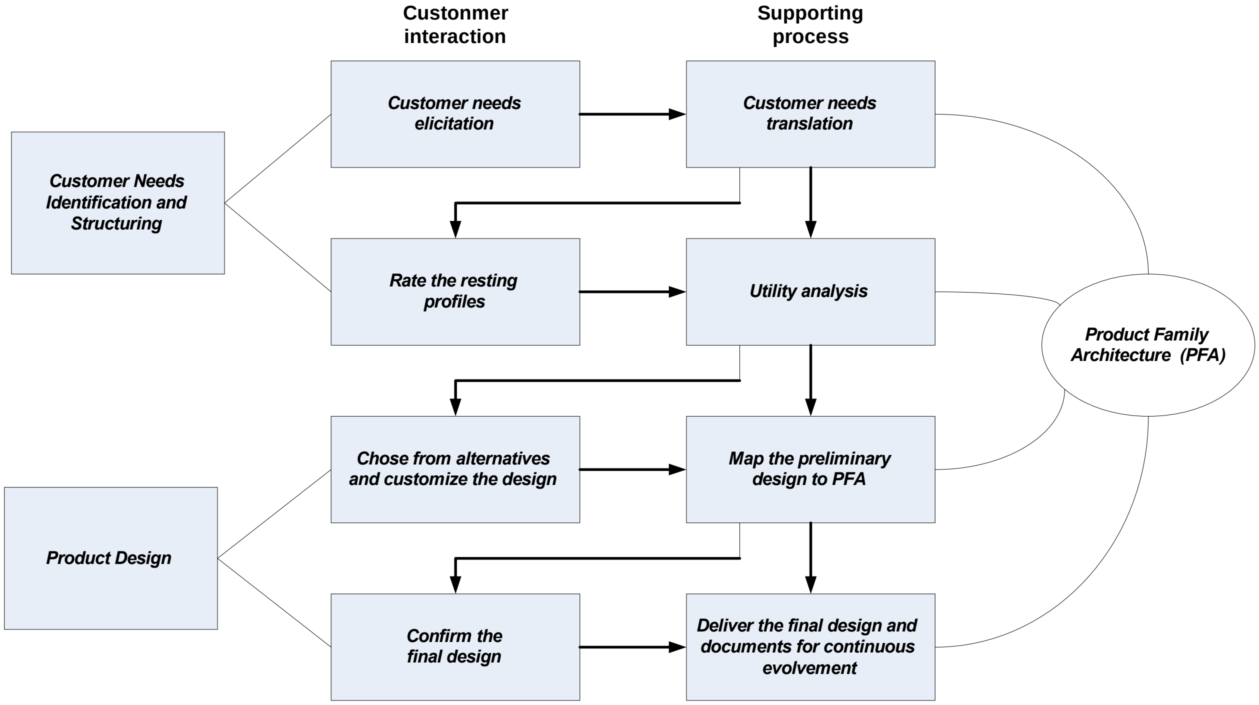

Figure 6 Design by Customer according to [7]

In *Product Design* stage customers are enabled to alter and improve products interactively and so to participate in the product definition process. Customers are presented a product configurator, in which a set of product attributes and their possible values are presented for selection and modification. Here configuration is referred to the process of choosing different attributes and attribute values and combining them into a final product. The *Design by Customer* approach could be obtained on Fig. 6.

INFORMATION TECHNOLOGIES SUPPORTING DBC

According to [12] the computer-mediated market will accelerate the process of customization through its technologies. *The Internet* provides new channels for promoting products and making sales in B2B market segment and so becomes an important factor for business in a wide range of industrial branches. Considerable research in using the Internet for supporting the design and production process is already done [1,13]. *The Internet* enables customer to improve his involvement in the early stages of product development through interactive web-based platform customization as an extensions of product family design [1].

Other efficient information technology to facilitate design and customization and to improve customer involvement within product development is the *Virtual Manufacturing (VM). VM* goes beyond the scope of traditional modeling and simulation in CAD/CIM environment and is based on following three main principles:

- **Model and Simulate**, which means to do manufacturing activities „virtually in the computer“;
- **Predict and Evaluate**, which means to determine what would happen if the activities were actually carried out;
- **Make Improvements**, before the actual manufacturing is done.

The different *VM*-models are discussed in details in [14,15]. A simplified schematic comparison between the *Virtual and Classical Manufacturing* could be obtained from Fig. 7.

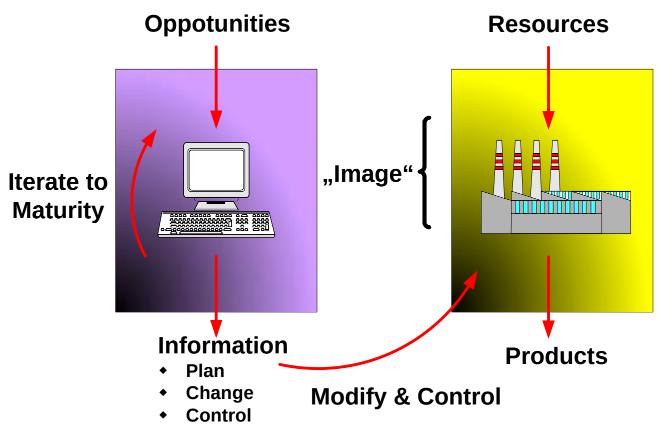

Figure 7 Virtual vs. Classical Manufacturing

Different scenarios for the use of *VM* in the small and medium-scale companies are reasonable, e.g. Component catalogues, Digital procurements, Electronic bids, Partner selection, Customization etc. Recently a trend for developing of so-called Virtual Products is established. Here the concept of “the virtual product” concerns not only the conventional computer aided planning and simulation of the developed products. According to the adopted definition “the virtual product” is a technical system, which allows instant and direct access and management from every PC, everywhere and on every stage and level of its life-cycle in order to increase the competitiveness and to guarantee the market share of the vendor through high diversity of the covered technical parameter ranges and possibility for promptly development and “materialisation” of pre-engineered “custom-tailored” solutions according to the individual clients needs. Here “access” is referred to a full duplex data flow performed by appropriate transfer protocol (usually TCP/IP) which can be configured and optimised on-line and independently of the place and time.

CASE STUDY DRIVESETS

For the purposes of a ongoing R&D-project with *Systec GmbH* studying the opportunity for introduction of some principles of so called “virtual manufacturing” in the small-to-medium-sized industrial companies a web-based framework for automation and facilitation of the design process using a systematic design approach and involving the customer within design process trough a “hybrid customisation” (a mix between tailored and standardized customization) was implemented. This framework was applied to support and maintain development of a “virtual family” of modular positioning and handling systems called *DriveSets*.

At the beginning a market study covering the EU-countries and Switzerland has found on the market segment for electric driven linear positioning and handling systems following:

- strong competition and deteriorated economical situation;
- need of complete “custom-tailored” solutions satisfying the specific application requirements of the customer
- wide offering of so called “driving packs” consisting of system integrated OEM-modules, most small-sized companies works only as system integrators;
- lack of common approach for systematic design and development of similar technical products.

According to [16] the systematic design approach provides an effective way to rationalize the development and production processes. Such design method is prerequisite for continuous computer support of the design by using stored data. Systematic processing makes possible consideration of cost and quality of the designed products on early stage, which enables better market chances. The developed hybride customization approach includes following basic elements:

- a web-based assistant for identification, structuring and mapping the customer requirements
- a product frame describing the parameters and features of each product family member derived on the ground of analysed customer requirements;
- a functional structure and UML-model of a modular handling system;
- classification of the functional units performing the single sub-functions of the systems;
- a morphological matrix to compose the functional unit set of the single sub functions in overall functional structures;
- an algorithm generating the possible variants of the system structures;
- a procedure for selection of the optimal positioning system;

- validation
- an algorithm for automatic generation of 3D-model, technical documentation and web-presenting of the found positioning system.

For the purposes of a unique identification of the single representatives of the DriveSet-family the convention for the following the system properties groups was adopted (Table 4):

- **operating properties –** all parameters defining the system input and output;
- **structure properties –** they describe the spatial structure of the system and geometric relations between the system elements

The defined system properties excluding the stroke are coded with semantic code. Through their systematic variation the set of the possible variants is generated. These possible variants build the frame in which the *DriveSets*-family evolves.

Operating properties	Structure properties
Load carrying capacity: describes the capacity of the system to carry a definite load. That is the maximal paying load which the system could accelerate up to the maximal speed in 100 ms.	**Operating area:** describes the shape of the operating area where the system TCP could be positioned. The shape of the operating area is related to the type of the kinematical structure and number of the spatial axes.
Speed: indicates the maximal system speed.	**Design type:** indicates the spatial arrangement and fixing of the single mechanical modules: e.g. gentry.
Repeatability: indicates the repeatability class of the system.	**Stroke:** indicates the maximal stroke along a single spatial axis.

Table 4 System properties of the DriveSets-family

The above mentioned elemnts are grouped in four stages.

Within ***first stage*** the Voice of Customers is captured by the web-based assistant. The obtained data are processed, analysed and translated and structured in engineering specification. On the ground of the obtained results the values of each predetermined product family member mapped in the product family frame are identified.

Within ***second stage*** sets of functional entities for single family member performing the sub-functions are combined through a morphological matrix technique in complete functional structures. Physical, geometric and functional compatibility of the functional entities is tested through an additional compatibility matrix.

Within ***third stage*** a selection of the optimal positioning system for specific requirements and constraints is made.

Within ***fourth stage*** a graphic form model describing the physical characteristics of the proposed structure: e.g. spatial, geometric and topological data is built. Tests are run through simulation to determine whether the intended purposes are satisfied by the found structure. After validation the proposed system configuration is saved in a database including all ready virtual positioning system. The technical documentation and HTML-code for web-representation of the new positioning system are generated at the end of the working cycle.

The presented approach was tested within development of *DriveSet*-family in *Systec E+S GmbH*. *Drive Sets* were designed as a scalable frame based parametric range of modular linear positioning systems with application in the industrial and laboratory automation, evolved through the integration of OEM-components (e.g. Fig. 8). *DriveSets* form a “virtual product family” in accordance with the predefined sets of systems properties (*load carrying capacity*, *maximum speed*, *repeatability*, *operating area*, *design type*, *stroke*) described as a product frame. Their specific value for each family member is determined at the design phase on ground of the mapped customer requirement and constraints providing a sort of ***tailored customization***. Every unique property combination obtains a single number identifying the correspondent representative of the family (see Fig.9). The network model of the DriveSets-family frame could be seen on Fig.10. In this manner some 144 basic structures were specified.

Figure 8 Virtual *DriveSet*

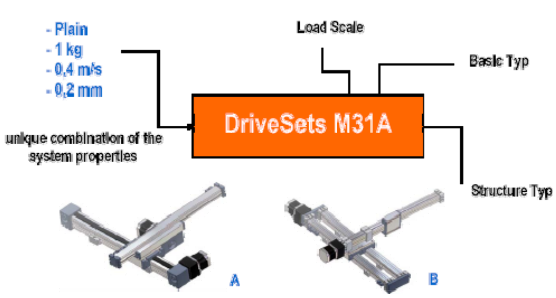

Figure 9 Identification of *DriveSets*

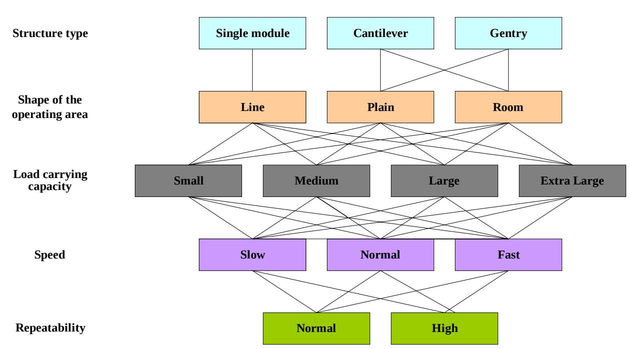

Figure 10 Network model of *DriveSets*

Within *Assembly stage* the customer could select among these "virtual existing" pre-engineered basic structures and find the system most appropriate for his specific needs using a simple selection procedure in n-dimensional system feature space (supported by hard copy catalogue or online). Further he can choose the stroke for every single axis of the system. 10 standard stroke lengths are available for every system axis. Various additional properties of the system like as cable chains, control unit type, material etc. are optional for the customer and enable him to perform a sort of standartized customization.

A prototype of web-based framework facilitating the generation and selection of the optimal configuration and acting as PPS of the product family is implemented. It is based on the classical 3-layer mode and includes:

- GUI for data input (front end client)
- Computing and optimization algorithm (server)
- Database at back-end
- 3D-models generation module using SolidWorks environment
- a set of VBA- macros for automatic generation of product documentation and code for web representation. Fig. 12 shows the software architecture and data flow within the system.

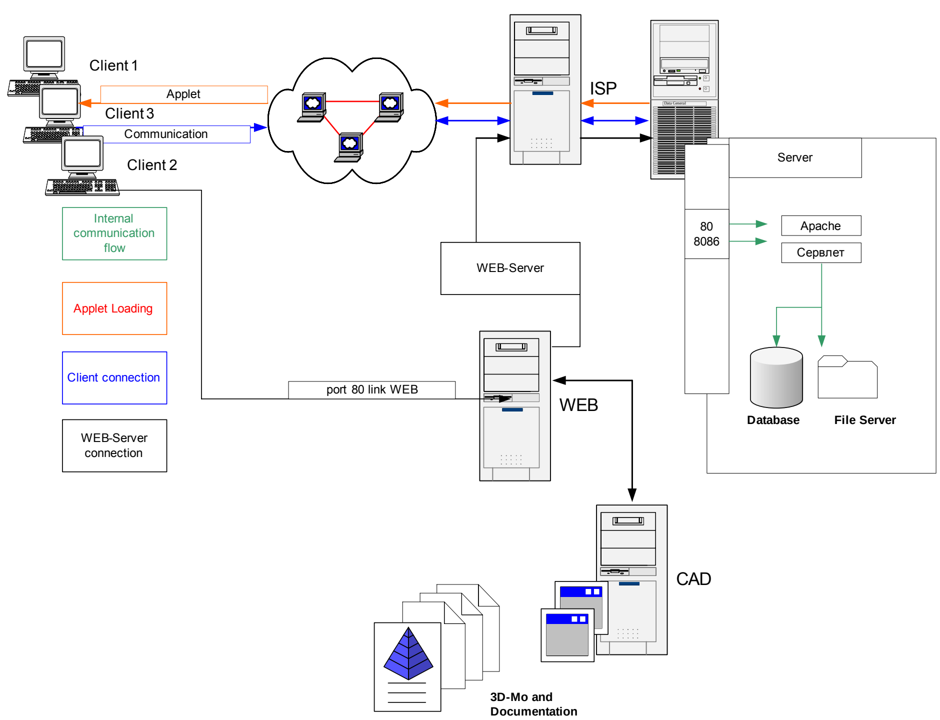

Figure 11 System architecture and data flows

GUI is implemented as wizard and the data input is performed within the user web-browser (Fig.12 and Fig.13)

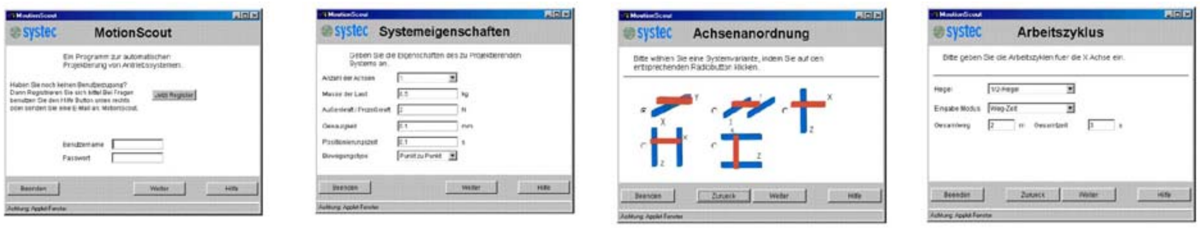

Figure 12 Screen-shots of the GUI used in the input wizard

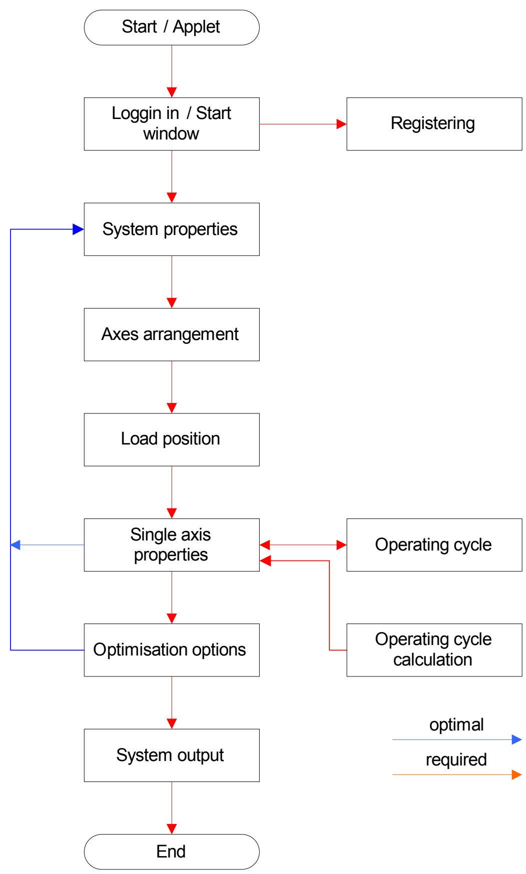

Figure 13 Navigation in the input wizard

The Java-applet provides the communication flow with the server and the database. The relational database (Fig.14) contains all necessary data for the computation and is linked with the PDS-database as a slave. At the end of the work cycle a 3D form model is generated is used for crash-tests, FEM-analysis etc, the technical documentation and code for web representation of the found systems are generated.

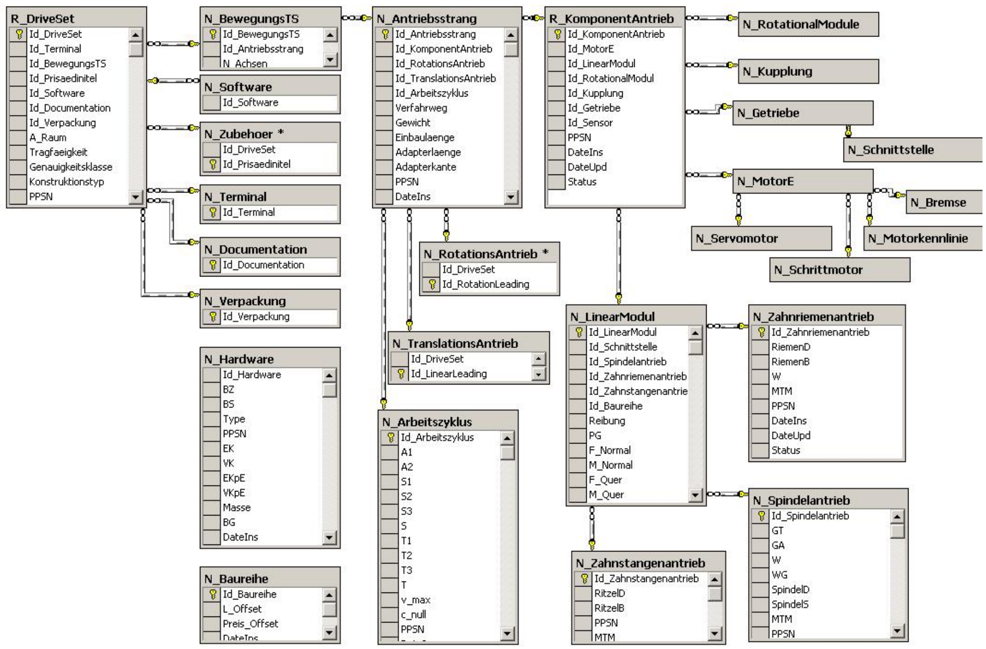

Figure 14 Relational Data Model of the *DriveSets*

CONCLUSION

In order to enhance the effectiveness of product development process and to reduce time to market, it has become imperative to connect customers directly as an integral part of the design process. This paper proposes a systematic approach to elicit customer needs and get customers involved in the different stages of the design process of a virtual product family of modular handling systems. Customers are able to directly participate in the product design by expressing their preferences in selecting product attributes and their values. This approach allows customers to be actively involved in the product definition process rather than passively receive the end product designed by the producer. Deployment of the presented design approach has some advantages in comparison with the conventional methods as follows:

- Consumers' knowledge and direct participation in the design process reduces the effort and saves time in respect to the solving of the design problem by providing valuble product information;
- cuts off the cost within development stage up to 40%;
- allows transformation toward desing-sell-make business cycle;
- is innovative and possesses improving potential and wide application field;
- was successfully tested in solving of real-world design problem within Systec E+S GmbH.

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